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No. 215

THE CONTROLS OF AN AIRPLANE.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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THE CONTROLS OF AN AIRPLANE.*

By Edward P. Warner.

There are six possible motions of a free body in space, and an airplane, which is as free as anything well can be, is capable of exhibiting them all, singly or collectively. The airplane may move forward, up and down, or sideways, and it can also rotate around any one of the three axes, pitching, rolling and yawing or turning. There are, therefore, six different things which the pilot must control, but, fortunately, it is unnecessary to use six distinctly-operated controlling mechanisms for the purpose.

The longitudinal and vertical motions are dependent on the speed of the airplane and the inclination of the path of its flight and the control over them is therefore indirect. The speed of the airplane depends on the angle at which the air meets the wings, and that in turn is governed by the same control which regulates the pitching motions. The inclination of the flight path at a given speed depends on the power delivered by the engine, and so on the setting of the throttle. If the throttle is partly closed the engine power becomes insufficient to pull the airplane along the path previously followed, and the machine will nose down until the angle of travel is such that gravity assists in pulling the airplane through the air, the gain from that source just balancing the loss

* From Christian Science Monitor.

of propeller thrust as the result of slowing down the engine.

Sideways Motions.

The third of the possible motions of the airplane as a whole along one of its axes is also indirectly the result of a rotation of the airplane, and can be controlled by modifying the rotation which causes it. It is quite evident that if the airplane is tilted or rolled when flying steadily in a straight line, one wing being raised, the machine will start to slide toward the low side. Similarly, if the angle of bank, or the steady tilt, when turning is too large, the airplane will slide in toward the center of the circle which it is describing, while if the angle is too small there will be a skid away from the center, as a racing automobile will skid on the turns on an insufficiently banked track. All sideways motions of the airplane are therefore the result of too much or too little roll for the other conditions which exist at the time.

The six possible motions have thus been reduced to three, but no further reduction is possible. There must be three distinct controls on any three-dimensional vehicle, unless the natural stability with respect to some of the motions is so great that the possibility of disturbances so large as to require the use of the pilot's controls to overcome them can be quite neglected. That is the case, for example, with the airship and the submarine, each of which has so much natural stability in rolling that the chance of turning over to the side may be considered as nonexistent. The number of controls is then reduced to two. There have been certain airplanes,

also, in which two controls were made to suffice, but only at the cost of a sacrifice of efficiency so great that the increased simplicity of the controlling mechanism has not been considered a great enough advantage to counterbalance the loss in performance. Such types have therefore never become popular, but the best modern airplanes have enough stability so that they will fly themselves for long periods of time without attention from the pilot, and it is only when close to the ground that all three of the controls really demand continuous attention.

Two Distinct Problems.

Granting that three distinct controls of some sort are necessary two distinct problems arise. The first has to do with the controls themselves and the way in which the air acts upon them, the second with the mechanism by means of which the pilot operates them.

For the control of pitch, an elevator, or movable horizontal surface of small size, is always used, and it is the invariable practice of the last few years to put it behind the wings, although the first airplane which ever flew successfully, the Wright airplane of 1903, and a number of its successors during the next ten years had the elevator located at the extreme front. A front elevator, like a front rudder, gives a more powerful control than one of the same size located an equal distance to the rear of the center of the airplane, but it interferes with stability and gets in the way of the propeller in what has now become the conventional power plant position, and it has, therefore, disappeared from modern design.

Aside from an elevator, placed either front or rear, few pitch-controlling expedients have ever been tried. Some of the German gliders have had the horizontal tail surface fixed to serve for stabilizing only, the longitudinal control being secured by rotating the wings themselves. That furnishes a very quick and positive means of changing the angle at which the wings meet the wind, but there is no assurance that the resulting change of the flight-path will be of the desired nature and amount. Certainly it will not be quick enough in turning the airplane as a whole to meet the maneuvering demands of a modern military machine. It is reported that gliders controlled entirely through the wings get at times into positions from which it is impossible to extricate them, the movement of the center of pressure of the force on the wings being such that, however the wings may be tilted, the angle of descent of the flight-path remains substantially unchanged.

Control by Weight Shifting.

Longitudinal control through the shifting of weight has also been tried occasionally. Impracticable on airplanes for many obvious reasons, that simple device is used with apparent satisfaction by the birds and served men very well in the early days of gliding experiments. The followers of Chanute and Lillienthal still launch themselves into the air on their light airplanes, which they can control only by swinging their feet fore and aft from side to side to shift the center of gravity toward the side which they desire to lower.

Rather curiously there is more difference of opinion as to the best means of directional than of longitudinal/^{control.} Every ship for many centuries has had a rudder, and the airplane might be expected to follow that precedent, It does so, to be sure, in standard design practice, but the rudder is sometimes experimentally replaced by some other device with quite satisfactory results.

A turn can evidently be produced by pushing the nose or tail of the airplane around to one side or by dragging one wing-tip forward or backward. A rudder, whether front or rear, works by the first of those methods, while the second can be used by fitting swinging panels at the wing-tips, in such a way that they can be rotated to offer an increased resistance on one side. From the point of view of efficiency the rudder is the better arrangement. Although the rear of the body and the wing-tips are about equally distance from the center of the airplane, and the force which must be applied to produce a turn is therefore the same in the two positions, the force on the rudder acts laterally at right angles to the direction of flight, while that on the wing-tips acts directly against the motion of the airplane and operates as a brake. It must be balanced by increased propeller thrust during the turn.

Swinging Wing-Tips.

The most successful application of swinging wing-tips for directional control, as of tilting wings for governing the longitudinal motions, has been made on gliders. One of the German gliders which competed at the Rhön meet last summer was notable for its use of

tilting wing-tips which served both to steer and to balance, the pilot having control over the two tips independently. By tilting the tips oppositely the airplane could be made to roll without turning, while setting one tip only at a rather large angle put the brakes on that side and caused the glider to swing around as though it were pivoting on the wing-tip, where the resistance had been introduced.

The third control is that which governs the angle of roll or serves to correct disturbances which result in the lowering of one wing and the raising of the other. There have been two general methods of accomplishing that, the wings being warped as a whole so that the angle of presentation becomes larger on the low than on the high side or auxiliary surfaces, known as ailerons, being used. Ailerons are so made that they can be pulled up or down to vary the lift, acting really in the same way as a warping wing but without the structural complications which result from the attempt to make the wings flexible. It used to be common practice, ten or twelve years ago, to mount the ailerons between the wings as independent members, but they are now hinged directly to the rear edge of the wing itself. This change was made to reduce the amount of additional structure required for the mounting of the control surfaces and also to increase their effectiveness. A movable surface is more powerful, in general, when it is immediately behind and in contact with a fixed surface than when it is placed by itself in free air, for pulling down the aileron, elevator, or whatever it may be has the

effect of "banking up" the air in front of it, as snow drifts deepest against a wall on the windward side. Just as the pressure of the weight of the snow on the ground is increased by the pressure of the wall, the air pressure on the fixed surface is modified in such a way as to add to the controlling effect when the movable part is turned up or down.

These are the principal types of control which have actually been tried. There is no doubt that modifications will be made and new devices suggested as time goes on, and very large airplanes, in particular, will require careful study in order that the controls may be operated with sufficient ease and quickness. At the present time, however, there is no evidence of really radical changes in prospect. The elevator, rudder, and aileron seem likely to continue to hold their own against all competitors.